United States Environmental Protection Agency | Office of Emergency and Remedial Response Washington, DC 20460 | Office of Research and Development Cincinnati, OH 45268
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EPA

# *Engineering Bulletin* Slurry Walls

## Purpose

Section 121(b) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandates the Environmental Protection Agency (EPA) to select remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable" and to prefer remedial actions in which treatment "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants, and contaminants as a principal element." The Engineering Bulletins are a series of documents that summarize the latest information available on selected treatment and site remediation technologies and related issues. They provide summaries of and references for the latest information to help remedial project managers, on-scene coordinators, contractors, and other site cleanup managers understand the type of data and site characteristics needed to evaluate a technology for potential applicability to their Superfund or other hazardous waste site. Those documents that describe individual treatment technologies focus on remedial investigation scoping needs. Addenda will be issued periodically to update the original bulletins.

## Abstract

Slurry walls are used at Superfund sites to contain the waste or contamination and to reduce the potential of future migration of waste constituents. In many cases slurry walls are used in conjunction with other waste treatment technologies, such as covers and ground water pump-and-treat systems.

The use of this well-established technology is a site-specific determination. Geophysical investigations and other engineering studies need to be performed to identify the appropriate measure or combination of measures (e.g., landfill cover and slurry wall) to be implemented and the necessary materials of construction based on the site conditions and constituents of concern at the site. Site-specific compatibility studies may be necessary to document the applicability and performance of the slurry wall technology. The EPA contact whose name is listed at the end of this bulletin can assist in the location of other contacts and sources of information necessary for such studies.

This bulletin discusses various aspects of slurry walls including their applicability, limitations on their use, a description of the technology including innovative techniques, and materials of construction including new alternative barrier materials, site requirements, performance data, the status of these methods, and sources of further information.

## Technology Applicability

Slurry walls are applicable at Superfund sites where residual contamination or wastes must be isolated at the source in order to reduce possible harm to the public and environment by minimizing the migration of waste constituents present. These subusurface barriers are designed to serve a number of functions, including isolating wastes from the environment thereby containing the leachate and contaminated ground water, and possibly returning the site to future land use.

Slurry walls are often used where a waste mass is too large for practical treatment, where residuals from the treatment are landfilled, and where soluble and mobile constituents pose an imminent threat to a source of drinking water. Slurry walls can generally be implemented quickly, and the construction requirements and practices associated with their installation are well understood.

The design of slurry walls is site specific and depends on the intended function(s) of the system. A variety of natural, synthetic, and composite materials and construction techniques are available for consideration when they are selected for use at a Superfund site.

Slurry walls can be used in a number of ways to contain wastes or contamination in the subsurface environment, thereby minimizing the potential for further contamination. Typical slurry wall construction involves soil-bentonite (SB) or cement-bentonite (CB) mixtures. These structures are often used in conjunction with covers and treatment technologies such as in situ treatment and ground water collection and treatment systems. Source containment can be achieved through a number of mechanisms including diverting ground water flow, capturing contaminated ground water, or creating an upward ground water gradient within the area of confinement (e.g., in conjunction with a ground water pump-and-treat system). Containment may also be achieved by lowering the groundwater level inside the containment area. This will help to reduce hydraulically driven transport (known as "advective transport") from the containment area. However, even if the hydraulic gradient is directed towards the containment area, transport of the contaminants (although thought to be minimal) is still possible. In many cases slurry walls are expected to be in contact with contaminants, therefore, chemical compatibility of the barrier materials and the contaminants may be an issue [1, p. 373-374].

The effectiveness of slurry walls and high density polyethylene (HDPE) geomembranes on soils and ground water contaminated with general contaminant groups is shown in Table 1. Examples of constituents within contaminant groups are provided in the "Technology Screening Guide for Treatment of CERCLA Soils and Sludges" [2]. This table is based on current available information or on professional judgment where no information was available. The proven effectiveness of the technology for a particular site or waste does not ensure that it will be effective at all sites or that the containment efficiencies achieved will be acceptable at other sites. For ratings used in this table, demonstrated effectiveness means that, at some scale, compatibility tests showed that the technology was effective or compatible with that particular contaminant and matrix.

**Table 1**
**Effectiveness of HDPE Geomembranes and Slurry Walls on General Contaminant Groups for Soil and Groundwater**

| | | *Effectiveness* | | |
|---|---|---|---|---|
| | | *HDPE* | *Slurry Walls* | |
| | *Contaminant Groups* | *Geomembranes* | *SB* | *CB* |
| *Organic* | Halogenated volatiles | ■ | ▼ | ▼ |
| | Halogenated semivolatiles | ■ | ▼ | ▼ |
| | Nonhalogenated volatiles | ■ | ▼ | ▼ |
| | Nonhalogenated semivolatiles | ■ | ▼ | ▼ |
| | PCBs | ■ | ▼ | ▼ |
| | Pesticides (halogenated) | ■ | ▼ | ▼ |
| | Dioxins/Furans | ▼ | ▼ | ▼ |
| | Organic cyanides | ■ | ▼ | ▼ |
| | Organic corrosives | ▼ | ❑ | ❑ |
| *Inorganic* | Volatile metals | ■ | ▼ | ▼ |
| | Nonvolatile metals | ■ | ▼ | ▼ |
| | Asbestos | ■ | ▼ | ▼ |
| | Radioactive materials | ▼ | ▼ | ▼ |
| | Inorganic corrosives | ❑ | ❑ | ❑ |
| | Inorganic cyanides | ■ | ▼ | ▼ |
| *Reactive* | Oxidizers | ❑ | ❑ | ❑ |
| | Reducers | ▼ | ▼ | ▼ |

■ Demonstrated Effectiveness: Short-term effectiveness demonstrated at some scale.

▼ Potential Effectiveness: Expert opinion that technology will work.

❑ No Expected Effectiveness: Expert opinion that technology will not work.

The ratings of potential effectiveness and no expected effectiveness are both based on expert judgment. Where potential effectiveness is indicated, the technology is believed capable of successfully containing the contaminant groups in a particular matrix. When the technology is not applicable or will probably not work for a particular combination of contaminant group and matrix, a no-expected-effectiveness rating is given.

## Limitations

In the construction of most slurry walls it is important that the barrier is extended and properly sealed into a confining layer (aquitard) so that seepage under the wall does not occur. For a light, non-aqueous phase liquid a hanging slurry may be used. Similarly, irregularities in the wall itself (e.g., soil slumps) may also cause increased hydraulic conductivity.

Slurry walls also are susceptible to chemical attack if the proper backfill mixture is not used. Compatibility of slurry wall materials and contaminants should be assessed in the project design phase.

Slurry walls also may be affected greatly by wet/dry cycles which may occur. The cycles could cause excessive desiccation which can significantly increase the porosity of the wall.

Once the slurry walls are completed, it is often difficult to assess their actual performance. Therefore, long-term ground water monitoring programs are needed at these sites to ensure that migration of waste constituents does not occur.

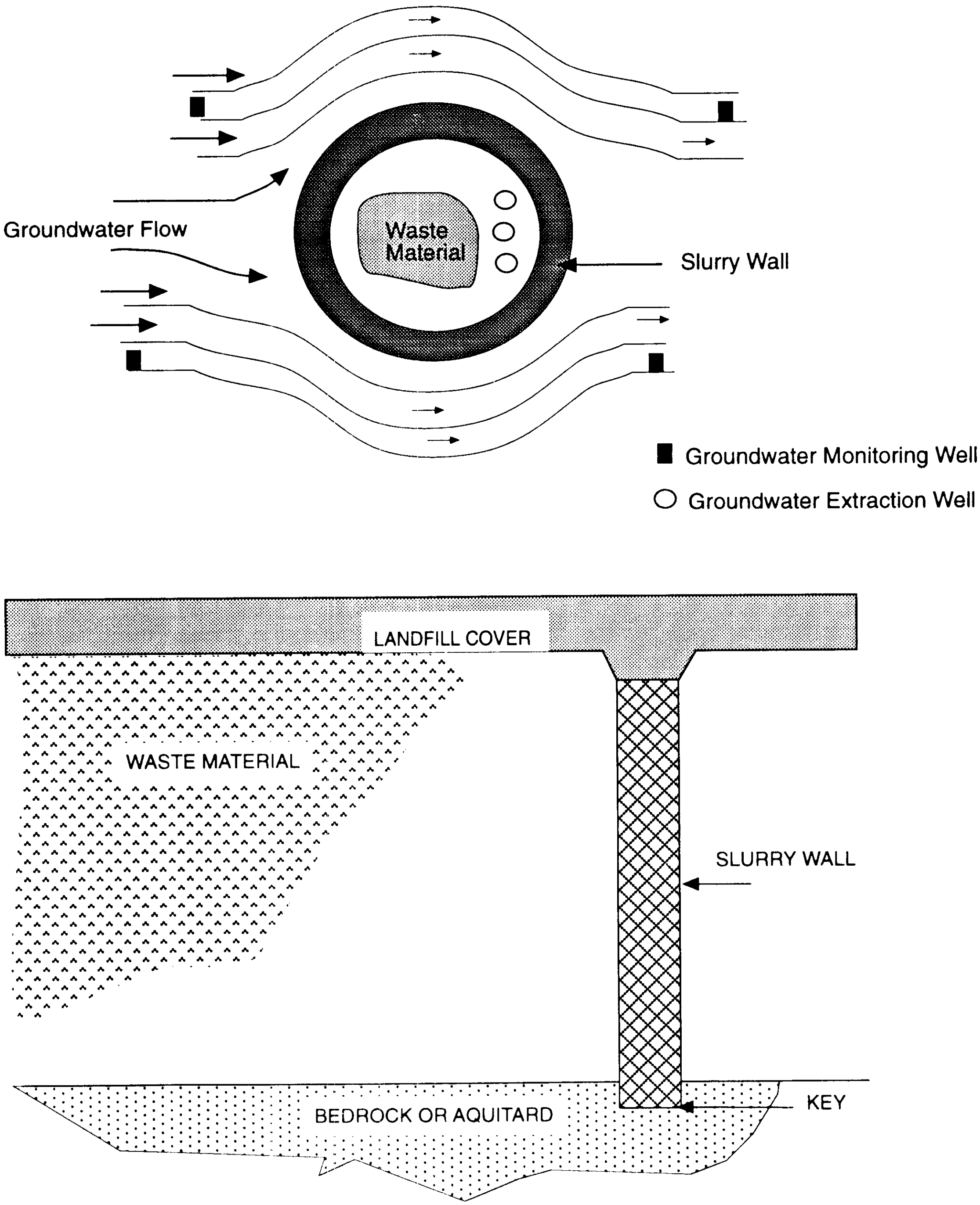
## Technology Description

Low-permeability slurry walls serve several purposes including redirecting ground water flow, containing contaminated materials and contaminated ground water, and providing increased subsurface structural integrity. The use of vertical barriers in the construction business for dewatering excavations and building foundations is well established.

The construction of slurry walls involves the excavation of a vertical trench using a bentonite-water slurry to hydraulically shore up the trench during construction and seal the pores in the trench walls via formation of a "filter cake" [3, p. 2-17]. Slurry walls are generally 20 to 80 feet deep with widths 2 to 3 feet. These dimensions may vary from site to site. There are specially designed "long stick" backhoes that dig to 90 foot depths. Generally, there will be a substantial cost increase for walls deeper than 90 feet. Clam shell excavators can reach depths of more than 150 feet. Slurry walls constructed at water dam projects have extended to 400 feet using specialized milling cutters. Depending on the site conditions and contaminants, the trench can be either excavated to a level below the water table to capture chemical "floaters" (this is termed a "hanging wall") or extended ("keyed") into a lower confining layer (aquitard) [3, p. 3-1]. Similarly, on the horizontal plane the slurry wall can be constructed around the entire perimeter of the waste material/site or portions thereof (e.g., upgradient,

* [reference number, page number]

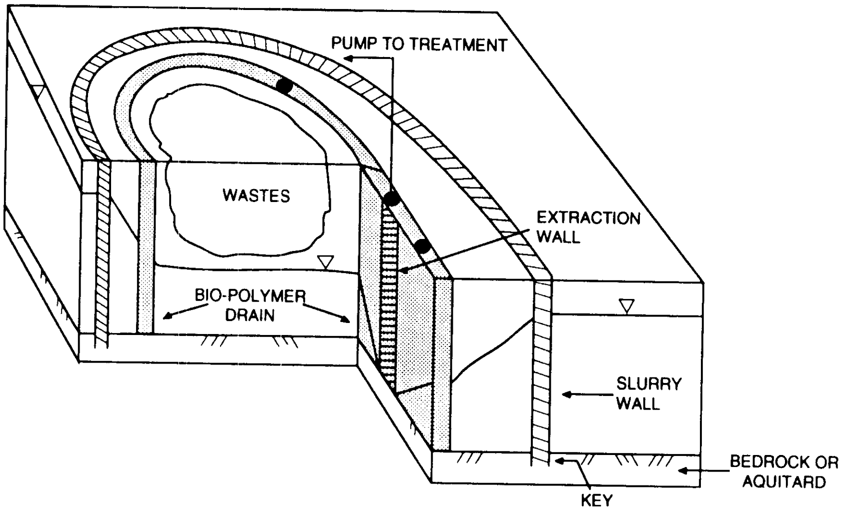
**Figure 1**
**Aerial and Cross-section View Showing Implementation of Slurry Walls (4)**




downgradient). Figure 1 diagrams a waste area encircled by a slurry wall with extraction and monitoring wells inside and outside of the waste area, respectively along with a cross-section view of a slurry wall being used with the landfill cover technology [4, p. 1].

The principal distinctions among slurry walls are differences in the low-permeability materials used to fill the trenches. The ultimate permeability of the wall is controlled by water content and ratios of bentonite/soil or bentonite/cement. In the case of a SB wall, the excavated soil is mixed with bentonite outside of the trench and used to backfill the trench. During the construction of a CB slurry wall, the CB mixture serves as both the initial slurry and the trench backfill. When this backfill gels (SB) or sets (CB), the result is a continuous barrier with lower permeability than the surrounding soils. A landfill cover, if

**Figure 2**
**Schematic Diagram of Typical Slurry Wall and Bio-polymer Slurry Trench (9)***




* Drawing not to scale

employed, must extend over the finished slurry wall to complete the containment and to avoid desiccation.

Soil-bentonite slurry walls are the most popular since they have a lower permeability than CB walls, and are less costly [3, p. 1-6] [5, p. 2]. Attapulgite may also be used in situations where the bentonite is not compatible with the waste [5, p.16]. A newer development is the use of fly ash as a high carbon additive not only to lower the permeability of the SB but also to increase the adsorption capacity of the SB with respect to the transport of organic chemicals [6, p. 1][7, p. 444]. Permeabilities of SB walls as low as 5.0 x $10^{-9}$ cm/sec have been reported although permeabilities around 1 x $10^{-7}$ cm/sec are more typical [3, p. 2-28]. The primary advantage of the CB wall is its greater shear strength and lower compressibility. CB walls are often used on unstable slopes and steep terrain or where soils of low permeability are not accessible [3, p. 2-40]. The lowest permeabilities of CB walls are typically 1 x $10^{-6}$ cm/sec or greater [3, p. 2-42] [5, p. 14]. It should be noted that organic and inorganic contaminants in ground water/leachate can have a detrimental effect on bentonite and the trench backfill material in both SB and CB walls. Therefore, it is imperative that a compatibility testing program be conducted in order to determine the appropriate backfill mixture.

Composite slurry walls incorporate an additional barrier, such as a geomembrane, within the trench to improve impermeability and chemical resistance. The geomembranes often are plastic screens that are comprised of HDPE pile plank sections which lock together. The locking mechanism is designed to minimize the leakage of the contaminated ground water. Table 2 shows one vendor's experience in using HDPE as a geomembrane [8]. The membrane: is easy to install; has a long life; and is resistant to animal and vegetation intrusion, microorganisms, and decay. Combining the membrane with a bentonite slurry wall may be the most effective combination. It is usually effective to construct the bentonite-cement slurry wall and then install the membrane in the middle of the wall. The toe of the membrane sheet is stabilized in the backfill material, cement, or in a special grout [5, p.4]. The installation is reported to be effective in most every type of soil, is watertight and may be constructed to greater depths.

A relatively new development in the construction of slurry walls is the use of mixed-in-place walls (also referred to as soil-mixed walls). The process was originally developed in Japan. A drill rig with multi-shaft augers and mixing paddles is used to drill into the soil. During the drilling operation a fluid slurry or grout is injected and mixed with the soil to form a column. In constructing a mixed-in-place wall the columns are overlapped to form a continuous barrier. This method of vertical barrier construction is recommended for sites where contaminated soils will be encountered, soils are soft, traditional trenches might fail due to hydraulic forces, or space availability for construction equipment is limited. Both this method and a modified method termed "dry jet mixing" are usually more expensive than traditional slurry walls [5, p. 7] [9].

Another application of traditional slurry wall construction techniques is the construction of permeable trenches called bio-polymer slurry drainage trenches [10] [11]. Figure 2 diagrams a slurry wall and a bio-polymer slurry drainage trench constructed around a waste source; this will typically involve the use of a landfill cover in conjunction with the wall. Rather than restricting ground water flow, these trenches are constructed as interceptor drains or extraction trenches for collecting or removing leachate, ground water, and ground water-borne contaminants. These trenches also can be used as recharge systems. The construction sequence is the same as the traditional method described above. However, a biodegradable material (i.e., bio-polymer) with a high gel strength is used in the place of bentonite in the slurry, and the trench is backfilled with permeable materials such as sand or gravel. Once the trench is completed, the bio-polymer either degrades or is broken with a breaker solution that is applied to the trench. Once the bio-polymer filter cake is broken the surrounding soil formation returns to its original hydraulic conductivity. Groundwater collected in the trench can be removed by use of an extraction well or other collection system installed in the trench [10]. A bio-polymer trench can be used in conjunction with an SB or CB slurry wall to collect leachate or a contaminated plume within the wall (similar to the function of a well-point collection system). A geomembrane also can be installed with the bio-polymer wall to restrict ground water flow beyond the bio-polymer wall.

Grouting, including jet grouting, employs high pressure injection of a low-permeability substance into fractured or unconsolidated geologic material. This technology can be used to seal fractures in otherwise impermeable layers or construct vertical barriers in soil through the injection of grout into holes drilled at closely spaced intervals (i.e., grout curtain) [5, p.8] [12, p. 5-97]. A number of substances can be used as grout including cement, alkali silicates, and organic polymers [12, p. 5-97 – 5-101]. However, concerns surround the use of grouting for the construction of vertical barriers in soils because it is difficult to achieve and verify complete permeation of the soil by the grout. Therefore, the desired low permeabilities may not be achieved as expected [5, p.8] [13, p. 7].

## Site Requirements

Treatment of contaminated soils or other waste materials requires that a site safety plan be developed to provide for personnel protection and special handling measures.

The construction of slurry walls requires a variety of construction equipment for excavation, earth moving, mixing, and pumping. Knowledge of the site, local soil, and hydrogeologic conditions is necessary. The identification of underground utilities is especially important during the construction phase [8].

In slurry wall construction, large backhoes, clamshell excavators, or multi-shaft drill rigs are used to excavate the trenches. Dozers or graders are used for mixing and placement of backfill. Preparation of the slurry requires batch mixers, hydration ponds, pumps, and hoses. An adequate supply of water and storage tanks is needed as well as electricity for the operation of mixers, pumps, and lighting. Areas adjacent to the trench need to be available for the storage of trench spoils (which could potentially be contaminated) and the mixing of backfill. If excavated soils will not be acceptable for use in the slurry wall backfill suitable backfill material must be imported from off the site. In the case of CB walls, plans must be made for the disposal of the spoils since they are not backfilled. In marked contrast, deep soil mixing techniques require less surface storage area, use less heavy equipment, and may produce a smaller volume of trench spoils.

## Performance Data

Performance data presented in this bulletin should not be considered directly applicable to all sites. A number of variables such as geographic region, topography, and material availability can affect the walls performance. A thorough characterization of the site and a compatability study is highly recommended.

At the Hill Air Force Base in northern Utah the installation of a slurry wall, landfill covers, groundwater extraction and treatment, and monitoring was implemented to respond to ground water and soil contamination at the site. The slurry wall was installed along the upgradient boundary on three sides of Operable Unit No. 1 to intercept and divert ground water away from the disposal site. Operable Unit No. 1 consists of Landfill No. 3, Landfill No. 4, Chem Pits No. 1 and 2, and Fire Training Area No. 1. Shallow perched groundwater and soils present were contaminated with halogenated organics and heavy metals. The performance of the slurry wall had been questioned because it was not successfully keyed into the underlying clay layer. This oversight was attributed to both the inadequate number and depth of soil borings. The combination of landfill caps, slurry wall, and ground water extraction and treatment has resulted in a significant reduction in the concentrations of organics and inorganics detected seeping at the toe of Landfill No. 4. Organics were reduced to levels below 5 percent of their pre-remedial action levels and iron was reduced to 20 percent of its original observed concentration. Three seperate QA/QC projects were implemented to assess the in situ effectiveness of the slurry wall. The determination of ground water levels in monitoring wells on the inside and outside of the wall provided the most the useful data [14].

**Table 2**
**Relative Chemical Resistivity of an HDPE Geomembrane (8)[a]**

| | | | |
|---|---|---|---|
| ***Aromatic Compounds*** | | ***Inorganic Contamination*** | |
| Benzene | + | $NH_4$ | ++ |
| Ethylene Benzene | ++ | Fluorine | ++ |
| Toluene | + | CN | ++ |
| Xylene | ++ | Sulphides | ++ |
| Phenol | ++ | $PO_4$ | ++ |
| ***Polycyclic Hydrocarbons*** | | ***Other Sources of Contamination*** | |
| Naphthalene | ++ | Tetrahydrofurane | + |
| Anthracene | ++ | Pyrides | ++ |
| Phenanthrene | ++ | Tetrahydrothiophene | ++ |
| Pyrene | ++ | Cyclohexanone | ++ |
| Benzopyrene | ++ | Styrene | ++ |
| | | Petrol | ++ |
| | | Mineral Oil | ++ |
| ***Chlorinated Hydrocarbons*** | | ***Pesticides*** | |
| Chlorobenzenes | + | Organic Chlorine Compounds | ++ |
| Chlorophenols | ++ | Pesticides | ++ |
| PCBs | ++ | | |

**Key:** ++ Good Resistance
\+ Average Resistance

[a] Adapted from vendor's marketing brochure

At the Lipari Landfill Superfund Site in New Jersey, a SB slurry wall was installed to encircle the landfill. A landfill cover, incorporating a 40 mil HDPE geomembrane, also was installed at the site. Heavy rains and snowmelt prior to the complete cap installation resulted in the need to perform an emergency removal (i.e., dewatering). Several years after completion of the slurry wall and landfill cover their effectiveness was evaluated during a subsequent feasibility study. The study concluded that the goal of an effective permeability of $1 \times 10^{-7}$ cm/sec had been achieved in the slurry wall. Monitoring wells will be located at least 5 feet from the slurry wall on the upgradient side and 7 feet on the down gradient side [15]. The combination of technologies being used along with the slurry wall appears to be effectively containing the waste and its constituents.

A SB slurry wall, up to 70 feet deep, was installed at a municipal landfill Superfund site in Gratiot County, Michigan. The slurry wall was needed to prevent leachate from migrating into the local ground water. Approximately 250,000 $ft.^2$ of SB slurry wall was installed at the site. The confirmation of achieving a goal of a laboratory permeability of less than $1 \times 10^{-7}$ cm/sec for the soil-bentonite backfill was reported by an independent laboratory [16].

A SB slurry wall, extending through three aquifers, was installed at the Raytheon NPL site in Mountain View, California. Soil and ground water at the site were contaminated with industrial solvents. Permeability tests performed on the backfilled material achieved the goal of $1 \times 10^{-7}$ cm/sec or less. Associated activities at the site included the rerouting of underground utilities, construction of 3-foot-high earthen berms around all work areas, construction of two bentonite slurry storage ponds ,and construction of three lined ponds capable of storing 300,000 gallons of storm water. A ground water extraction and stripping/filtration system is also in place at the site. The slurry wall, purposely, was not keyed into an aquitard so that the ground water extraction program would create an upward gradient, thus serving to further contain the contaminants. The system appears to be functioning properly with the implementation of the combination of the technologies [17] [18]. However, this is the exception rather than the rule.

## Technology Status

The construction and installation of slurry walls is considered a well-established technology. Several firms have experience in constructing this technology. Similarly, there are several vendors of geosynthetic materials, bentonitic materials, and proprietary additives for use in these barriers.

In EPA's FY 1989 ROD Annual Report [19] 26 RODs specified slurry walls as part of the remedial action. Of the RODs specifying slurry walls, 22 also indicated that covers would be used. Table 3 presents the status of selected superfund sites employing slurry walls.

While site-specific geophysical and engineering studies (e.g., compatibility testing of ground water and backfill materials) are needed to determine the appropriate materials and construction specifications, this technology can effectively isolate wastes and contain migration of hazardous constituents. Slurry walls also may be implemented rather quickly in conjunction with other remedial actions. Long-term monitoring is needed to evaluate the effectiveness of the slurry wall.

## EPA Contact

Technology-specific questions regarding slurry walls may be directed to:

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| | |
|---|---|
| Dr. David Daniel | University of Texas |
| Dr. Charles Shackelford | Colorado State University |
| Ms. Mary Boyer | SAIC |

**Table 3**
**Selected Superfund Sites Employing Slurry Walls (19)**

| *SITE* | *Location (Region)* | *Status* |
|---|---|---|
| Ninth Avenue Dump | Gary, IN (5) | In design phase |
| Outboard Marine | Waukegan, IL (5) | In operation |
| Liquid Disposal | Utica, MI (5) | In design phase |
| Industrial Waste Control | Fort Smith, AR (6) | In operation since 3/91 |
| E.H. Shilling Landfill | Ironton, OH (5) | In design phase |
| Allied/Ironton Coke | Ironton, OH (5) | In pre-design phase |
| Florence Landfill | Florence Township, NJ (2) | Design completed; remedial action beginning soon |
| South Brunswick | New Brunswick, NJ (2) | In operation since 1985 |
| Sylvester | Nashua, NH (1) | In operation since 1983 |
| Waste Disposal Engineering | Andover, MN (5) | In design phase |
| Diamond Alkali | Neward, NJ (2) | In pre-design phase |
| Hooker - 102nd St. | Niagra Falls, NY (2) | In remedial design phase |
| Scientific Chemical Processing | Carlstadt, NJ (2) | Completed 1992 |

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